TEST RESULTS OF A PORTABLE BATTERY PACK'S EFFECT ON THE OUTPUT OF A CESIUM BEAM FREQUENCY STANDARD

by

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ABSTRACT

Tests were performed on portable cesium beam frequency standards (portable clocks) to determine the effect of the discharging and charging of the portable battery pack on the output of the portable clock. The 1 PPS, 1 MH and 5 MHz outputs as well as temperature, humidity and external AC power status were monitored at 5 minute intervals. Although more tests must be run, some interesting observations can be reported. Variations in output may be the result of changes in temperature and regulated voltage caused by the discharging and charging of the battery pack. Not all cesium clocks have 1 PPS, 1 MHz and 5 MHz outputs that track together as closely as expected.

INTRODUCTION

As the result of a suggestion submitted under the Beneficial Suggestion Program of the Department of the Navy by Patrick Lloyd, we tested the effect of charging and discharging a battery pack of a portable clock. A portable clock consists of a cesium beam frequency standard (also called a cesium clock or an atomic clock) connected to a portable battery pack. Donald Lee Sliger built the test set. We had a very limited number of portable clocks available for this project. Also, the available portable clocks were relatively old. We continuously recorded the outputs and internal parameters of the portable clock under test as well as local temperature and relative humidity as the AC power was turned on and off. A block diagram of the test set-up (Figure 1), parts list (Figure 2), and graphs of the test data (Figures 3 through 12) are at the end of this paper.

The heading of each graph contains the portable clock serial number, the battery pack serial number, and the time the test was started (year-month-day-hour-minute-second). The abscissa of each graph is time expressed as Modified Julian Date (MJD) minus 46,000. Note that the data collection started shortly after the test was started. The residual graphs are plots of the data after subtracting a value "Y" computed from a linear slope, where $Y = m X + B$. Some residual graphs contain the term "drift." The term should be "slope."

Each figure of Figures 5, 7, 9, 11 and 12 contain different Residual plots of the same data. In each pair pair, the first plot is a residual in which data at the beginning of the test and data at the end of the test are used to compute the straight line used to compute the residual. (In Figure 11, both graphs use data for the straight line at end of the test.) In each pair, the second plot uses data at the beginning of the test and data just before turning off AC power to compute the straight line used to compute the residual values. (In Figure 12, both plots use data collected prior to turning the AC power to compute the straight line. Figure 12 complements Figure 11.)

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J. C. Hafele and R. E. Keating studied the changes in a cesium clock due to relativity effects (References 1 and 2). In 1971, Hafele and Keating flew four 5061 cesium clocks around the world twice; and in an effort to detect and eliminate phase shifts of the type reported here, they carefully intercompared hourly each clock with the others. They found that changes in a clock's frequency with respect to the others were correlated with such events as transfer of the clocks from one airplane to another, and with periods when AC power was removed. It is clear in light of the present results that the success of the Hafele-Keating experiment was due to their careful intercomparison of all four clocks and their assumption that if any non-relativistic phase shifts did occur, such shifts would not affect all clocks, or if the clock were affected, the phase shifts would not all be in the same direction.

Although relative humidity data was collected, it was not analyzed for this paper. The results of the study and analysis of the effects of relative humidity on the portable cesium clock will be reported in a future paper.

The purpose of this paper is to report that there are secondary effects caused by changing the power to the power supply which affect the operation of the portable cesium clock. The most obvious secondary effect is change in temperature. The secondary effect of change in voltage is not as obvious.

The First Tests

The first experiments collected data without any attempt to narrow the scope of the investigation. AC power was applied to the portable clock for approximately two hours and then turned off. The batteries of the portable clock were allowed to discharge until the continuous operation lamp went out. AC power was turned back on, the clock was reset, and the test continued for several more hours. We monitored the continuous operation lamp (which was also our source for measuring the regulated voltage), battery indicator lamp voltage, unregulated voltage, room humidity, and the temperature immediately above the cesium clock. We also compared the outputs of the portable clock with the DoD Master Clock. No attempt was made to calibrate the cables because we were only interested in changes in the phase of the outputs. For convenience we monitored only the 1 PPS and 1 MHz outputs (Figures 3 through 5). In later tests we also monitored the 5 MHz output.

Graphs of the First Difference and Residuals are included. First Difference graphs are included only for the first tests (Figures 3 and 4). The first difference is calculated by taking the current data value and subtracting the previous data value (at 5-minute measurement intervals). Initially, the residuals were calculated by taking a data point near the beginning of the test and near the end of the test, calculating a slope, and using the slope to compute the value subtracted from each data point.

Later Tests

The First Difference graphs were too noisy to contribute to the investigation and were not computed for the later tests. Also, there was no information useful to this investigation gathered after the continuous operation lamp went out. In later tests, AC power was reapplied to the portable clock before the continuous operation lamp went out. The amount of time the portable clock batteries were

allowed to discharge was set at seven hours.

The shape of the 1 MHz Residual graph was different from the 1 PPS graph (Figures 3 through 5 -- only Figure 5 in this paper is large enough to clearly see the difference in shape). As a result, the 5 MHz output was monitored in subsequent tests. Changes in the shape of the residual graphs appeared to be related to the changes in the temperature graph and changes in AC power status.

The method of calculating the residuals was changed. The slope was computed by using data at the beginning of the test and data at the time just before AC power was turned off.

The test was run for longer periods. We monitored the clock for at least eight hours before turning off AC power and for at least one day after turning on AC power.

Some of the 5 MHz graphs show a large discontinuity which is not valid. The apparent discontinuity is caused by the counter reaching a maximum value of 200 nS (for a 5 MHz signal) and jumping to zero. The jump has not been removed from the data in this paper. Jumps in data due solely to the operation of the counter will be subtracted from the data in future tests.

Temperature dropped when the AC power was turned off in all of the tests (Figures 3, 4, 6, 8, and 10). When the AC power was turned back on, the temperature rose to a level warmer than prior to turning off the AC power. When the duration of the tests were increased, the temperature returned to the level that existed before the AC power was turned off (Figures 6 and 10). Examination of the AC Status graphs, the Temperature graphs, and the Residual graphs indicate that there was a large change in the slope of the Residual when the AC power was turned off and the temperature decreased, a large change in the slope of the Residual when the AC power was turned on and the temperature increased, and a smaller change in the slope of the Residual when the temperature decreased to the level that existed prior to turning off the AC power (Figures 6, 7, 10, 11, and 12). Figures 4 and 5 show the changes in the Residual when AC power is turned off and on. However, the test did not run long enough to indicate what happens when the temperature decreases to the level prior to turning off the AC power. Temperature apparently rises above the level that existed prior to turning off the AC because heat is dissipated due to the charging of the batteries as well as due to the powering of the cesium clock. After the batteries are charged, the temperature returns to the level normal for running on AC power.

Figures 3, 4, 6, 8, and 10 indicate that there is a change in regulated and unregulated voltage that is associated with the AC power status. However, the change in regulated voltage is small, and it cannot be concluded from the graphs that the change in regulated voltage has a direct affect on the output of the cesium clock. After conferring with Hewlett Packard and learning that the voltage regulator board was changed in later models, the change in regulated voltage was included as one of the secondary effects that may affect the output of the cesium clock. More testing is needed.

The 1 PPS, 5 MHz and 1 MHz Residuals have different shapes (Figures 5, 7, 9, 11, and 12). Since the outputs are derived from the same frequency source, it is concluded that the output drivers contribute to the effect.

Future Test Plans

Tests will be run for longer periods of time. At least three days of data will be monitored before turning off AC power to establish a better baseline. Up to five days of data will be monitored after AC power is again turned on. The effects of humidity will be studied and analyzed.

Hewlett Packard has been contacted. There have been four production modifications by Hewlett Packard to the cesium clock. The most recent production modification was completed approximately one year prior to the start of the tests described in this paper. The voltage regulator board, the oven control board, the battery charger circuit, and the 1 PPS output circuit have been modified. Several of the portable clocks under test will have the old and new circuits swapped. Each clock will be tested several times for longer periods. As many different different portable clocks as possible will be tested.

SUMMARY AND CONCLUSIONS

1. Test results are preliminary. More data are needed.
2. Older portable clocks were used in the investigation.
3. Tests for longer periods are needed.
4. There is an observable effect on the output of a portable clock resulting from the secondary effects of changing the power to the clock and the charging and discharging of the batteries.
5. The effect is a result of the secondary effect of changes in temperature. It is not as clearly indicated that the effect is a result of the secondary effect of changes in regulated voltage.
6. The output buffers and drivers contribute to the effect observed.

REFERENCES

1. J. C. Hafele and R. E. Keating, Science, "Around-the-World Atomic Clocks: Predicted Relativistic Time Gains", Vol. 177, pp. 166-167, July 14, 1972.
2. J. C. Hafele and R. E. Keating, Science, "Around-the-World Atomic Clocks: Observed Relativistic Time Gains", Vol. 177, pp. 168-170, July 14, 1972.

Portable Clock Monitoring System

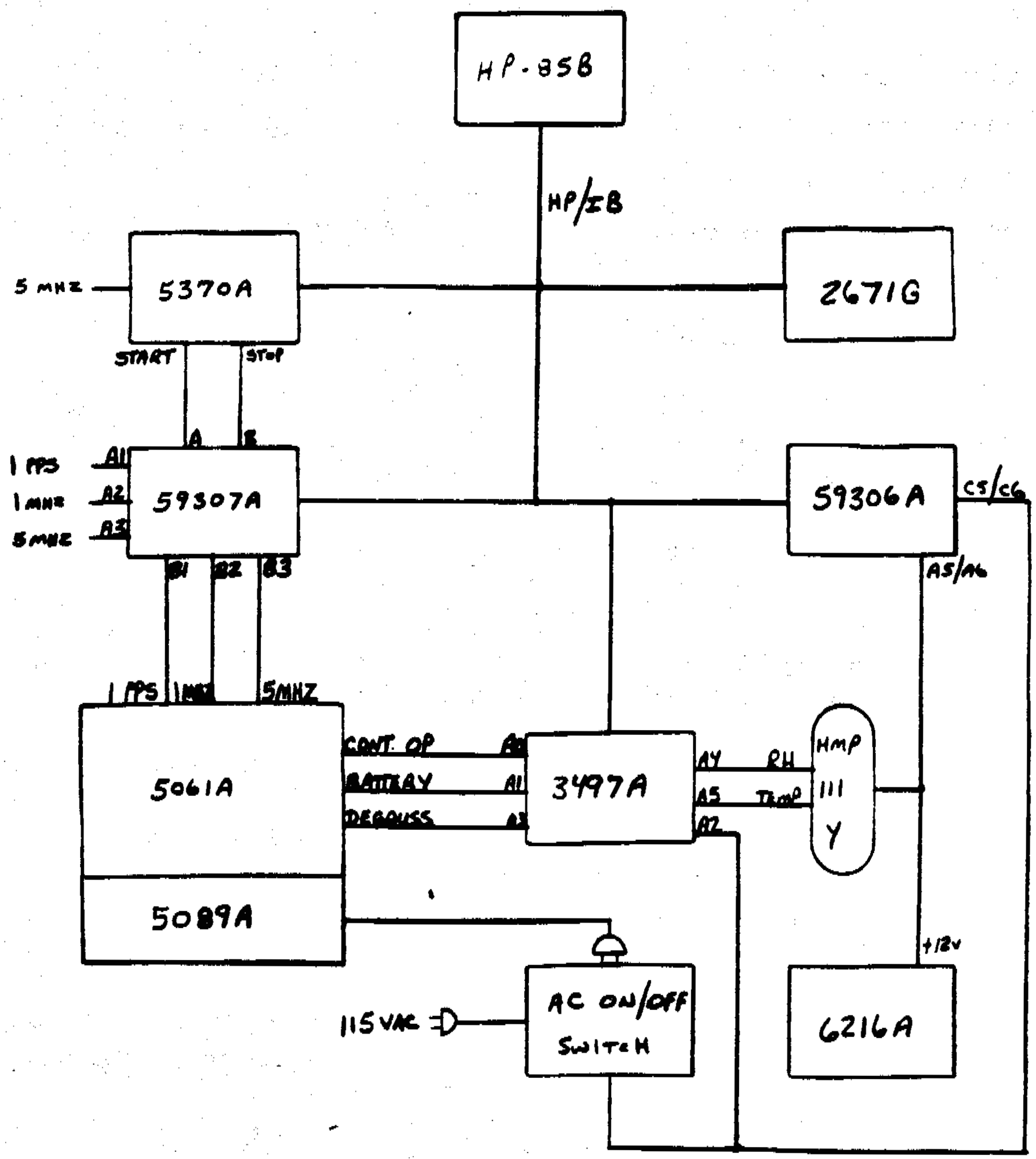


Figure 1

List of Equipment

2671G	Printer
3497A	Data Acquisition/Control Unit, Option 001/010
5061A	Cesium Beam Frequency Standard
5089A	Power Supply
5370A	Counter, Universal
59306A	Relay Actuator
59307A	VHF Switch
6216A	Power Supply (0-30v)
HMP111Y	Humidity & Temperature Probe
-------	NAVOBSY Switch Box

Note: All Equipment is Hewlett-Packard except the last two items.

Figure 2

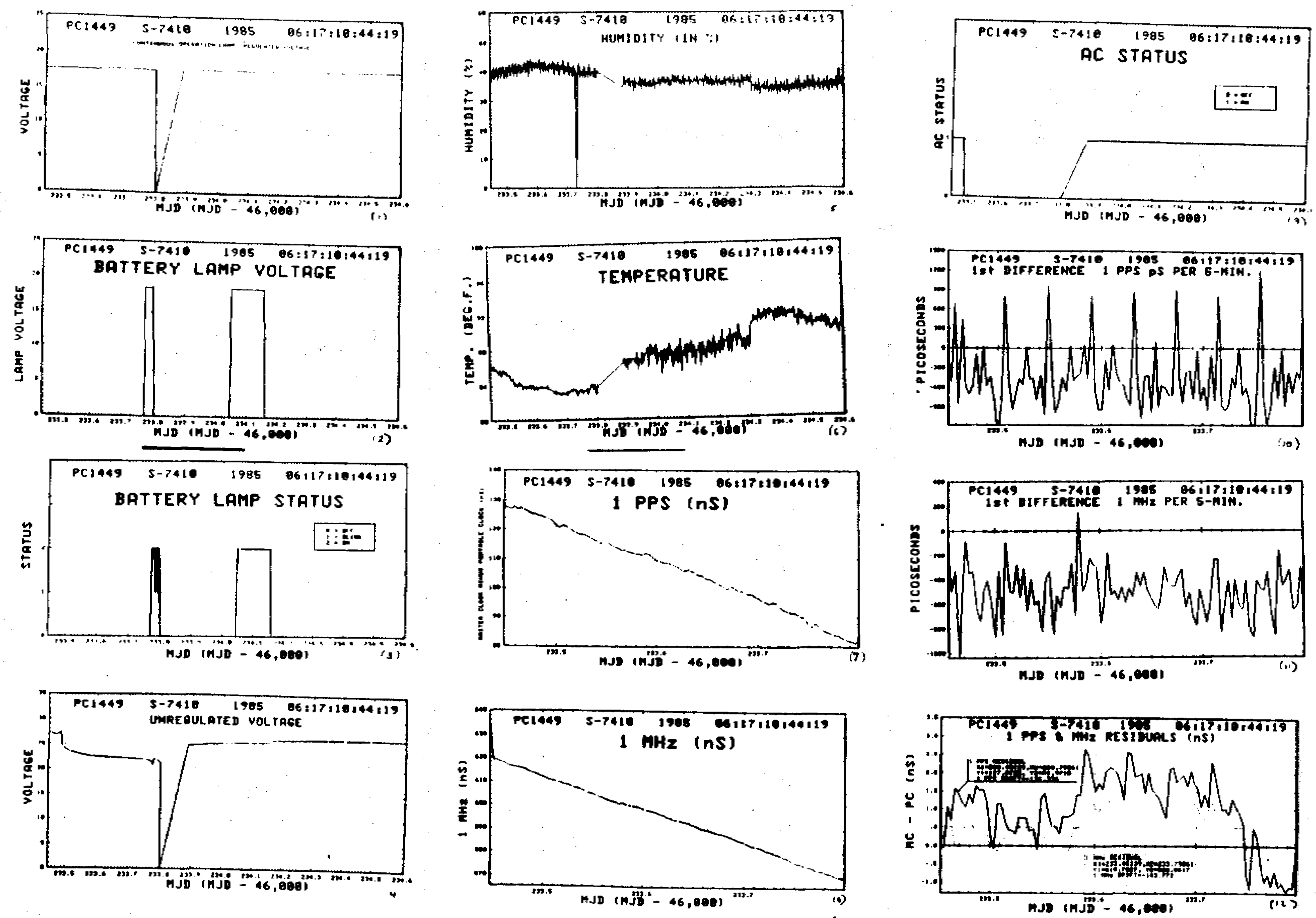

PC1449 S-7410 1985 06:17:10:44:19
VOLTAGE
MJD (MJD - 46,000)
BATTERY LAMP VOLTAGE
LAMP VOLTAGE
BATTERY LAMP STATUS
STATUS
UNREGULATED VOLTAGE
HUMIDITY (IN %)
HUMIDITY (%)
TEMPERATURE
TEMP. (DEG.F.)
1 PPS (nS)
1 MHz (nS)
AC STATUS
1st DIFFERENCE 1 PPS pS PER 5-MIN.
PICOSECONDS
1st DIFFERENCE 1 MHz PER 5-MIN.
1 PPS & MHz RESIDUALS (nS)
MC - PC (nS)

Figure 3

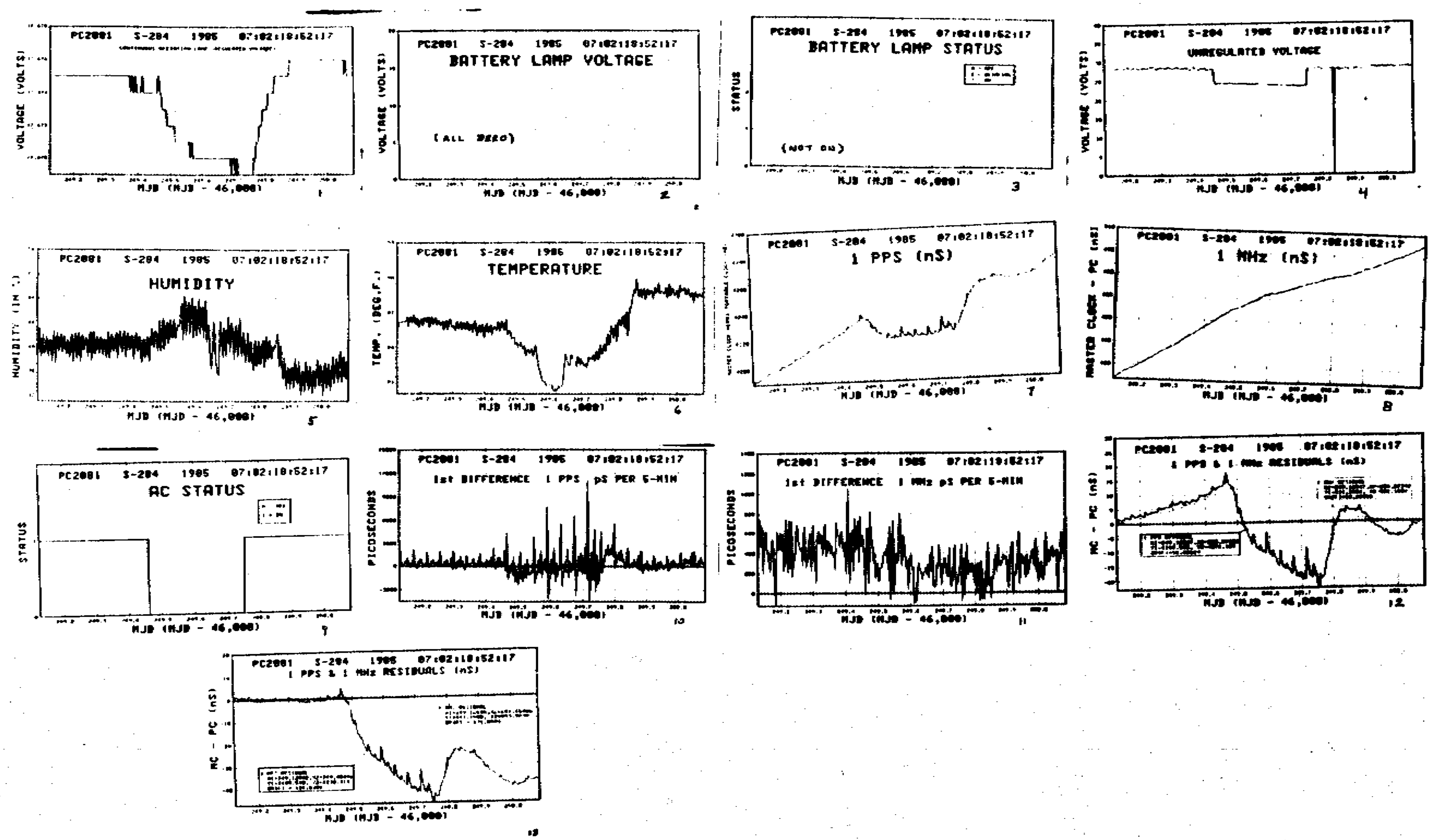
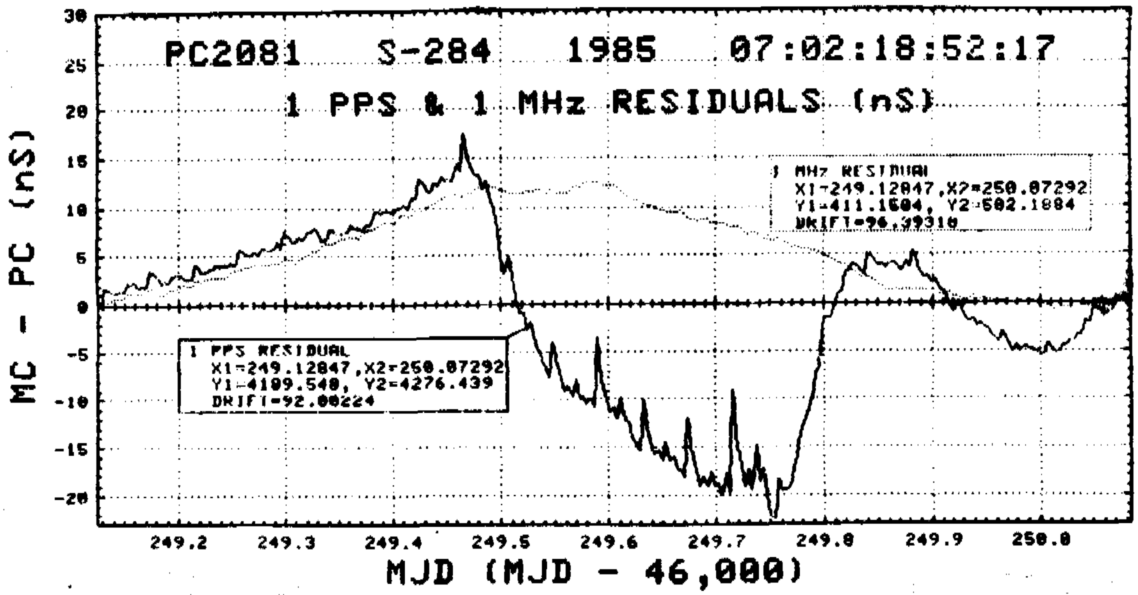

PC2001 S-284 1985 07:02:18:52:17
BATTERY LAMP VOLTAGE
(ALL ZERO)
BATTERY LAMP STATUS
(NOT ON)
UNREGULATED VOLTAGE
HUMIDITY
TEMPERATURE
1 PPS (nS)
1 MHz (nS)
AC STATUS
1st DIFFERENCE 1 PPS pS PER 5-MIN
1st DIFFERENCE 1 MHz pS PER 5-MIN
1 PPS & 1 MHz RESIDUALS (nS)
MJD (MJD - 46,000)
VOLTAGE (VOLTS)
STATUS
HUMIDITY (IN %)
TEMP. (DEG.F.)
MASTER CLOCK - PC (nS)
PICOSECONDS
MC - PC (nS)
1
2
3
4
5
6
7
8
9
10
11
12
13

Figure 4



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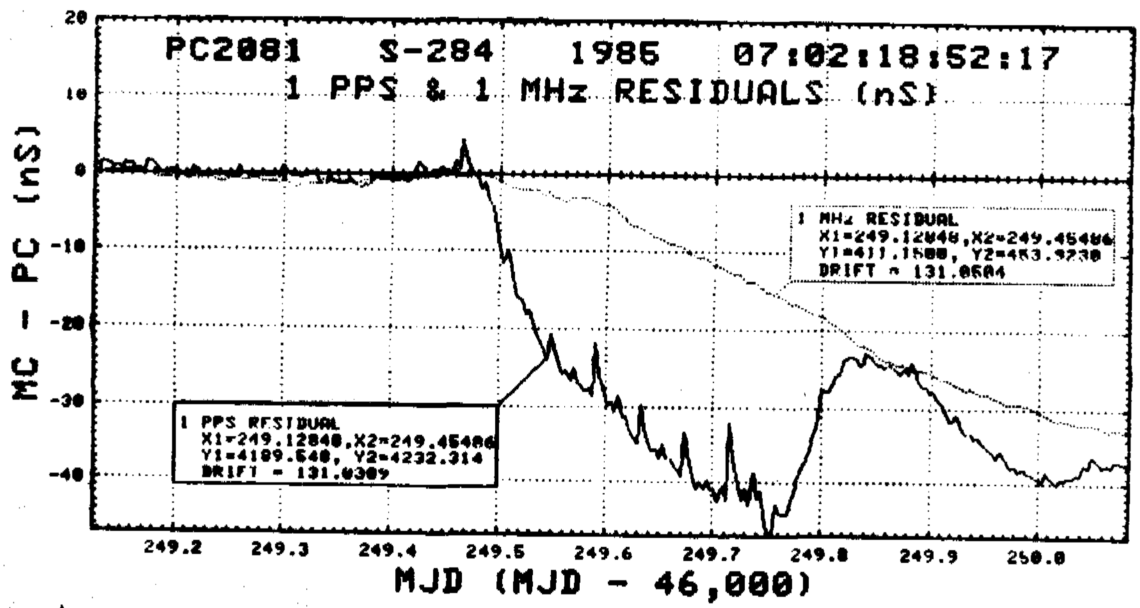

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Figure 5

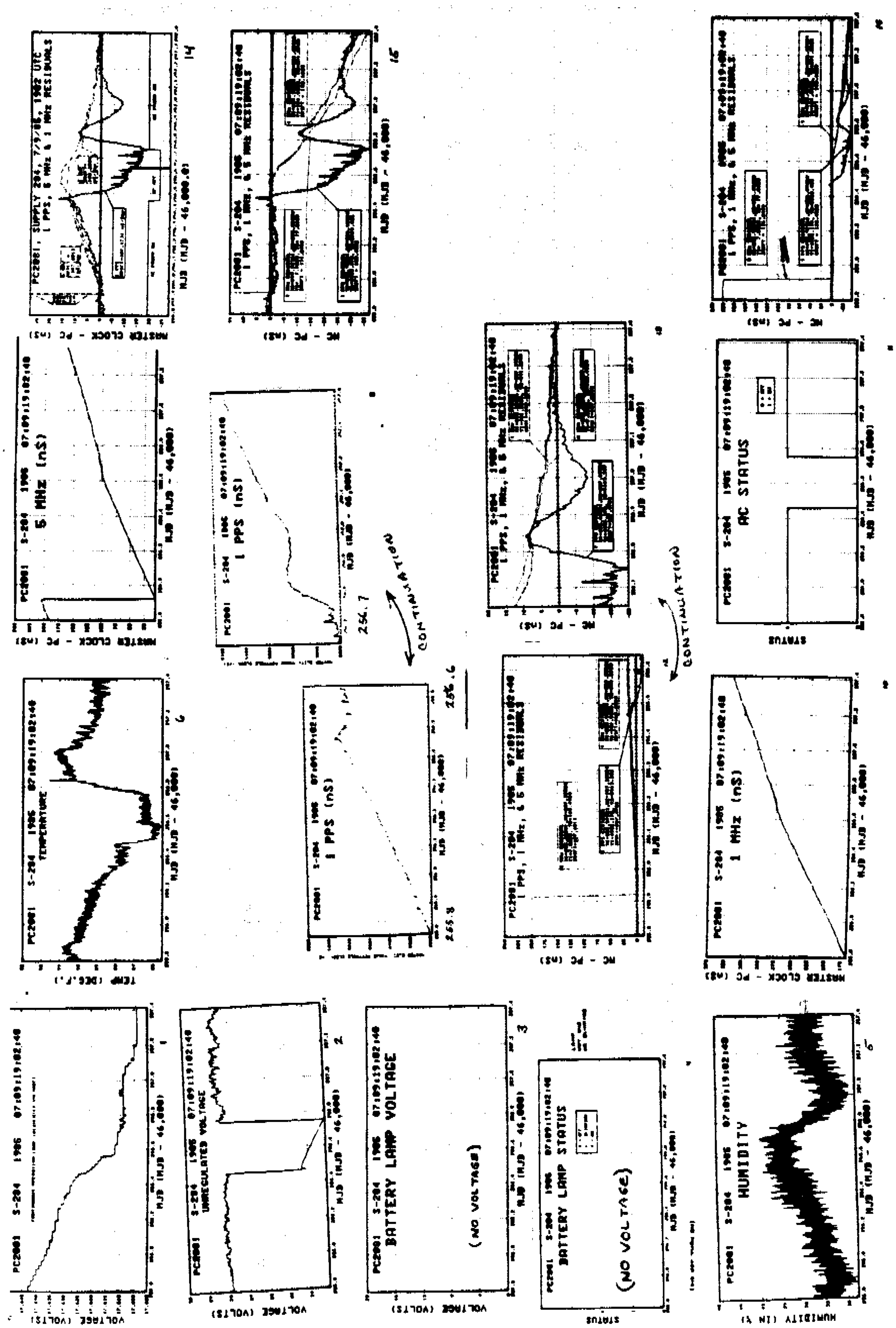
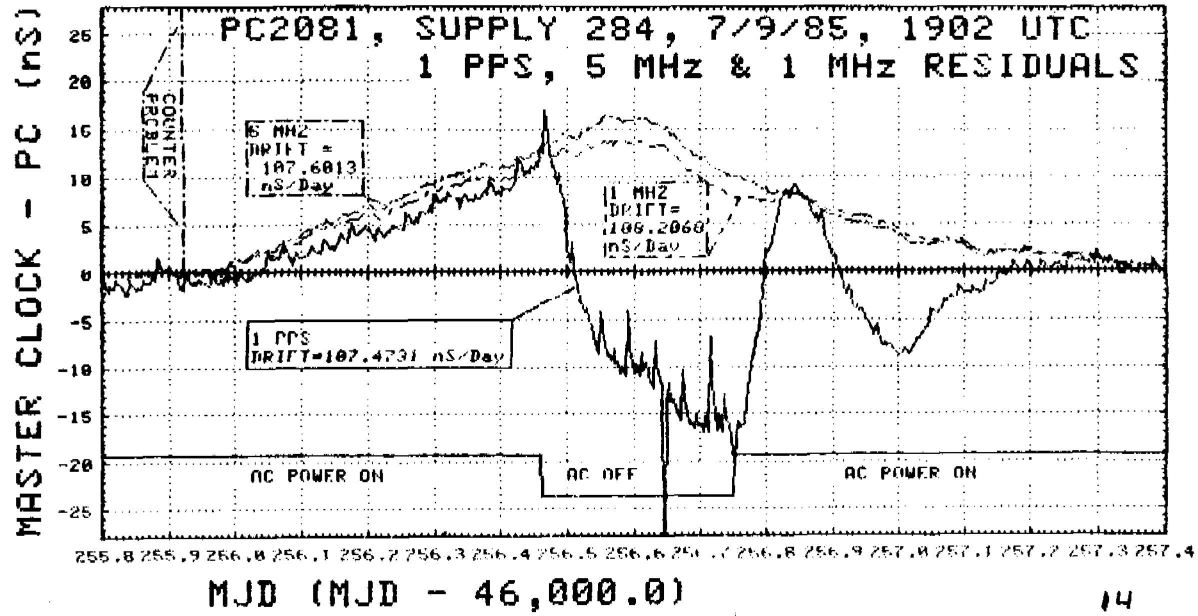


Figure 6



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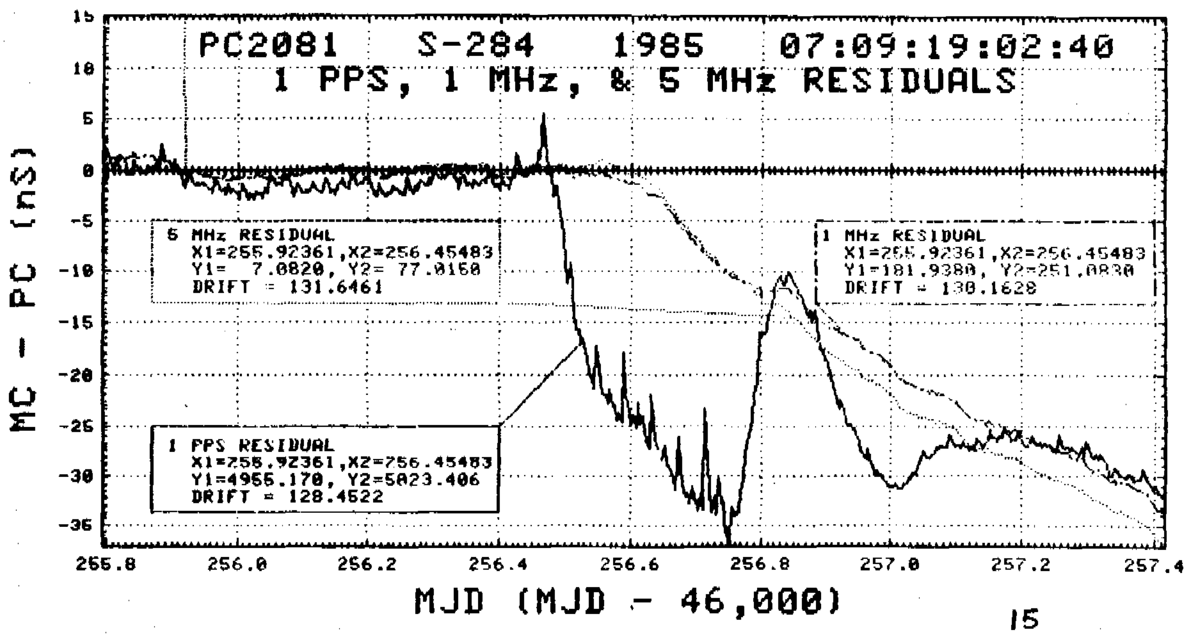

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Figure 7

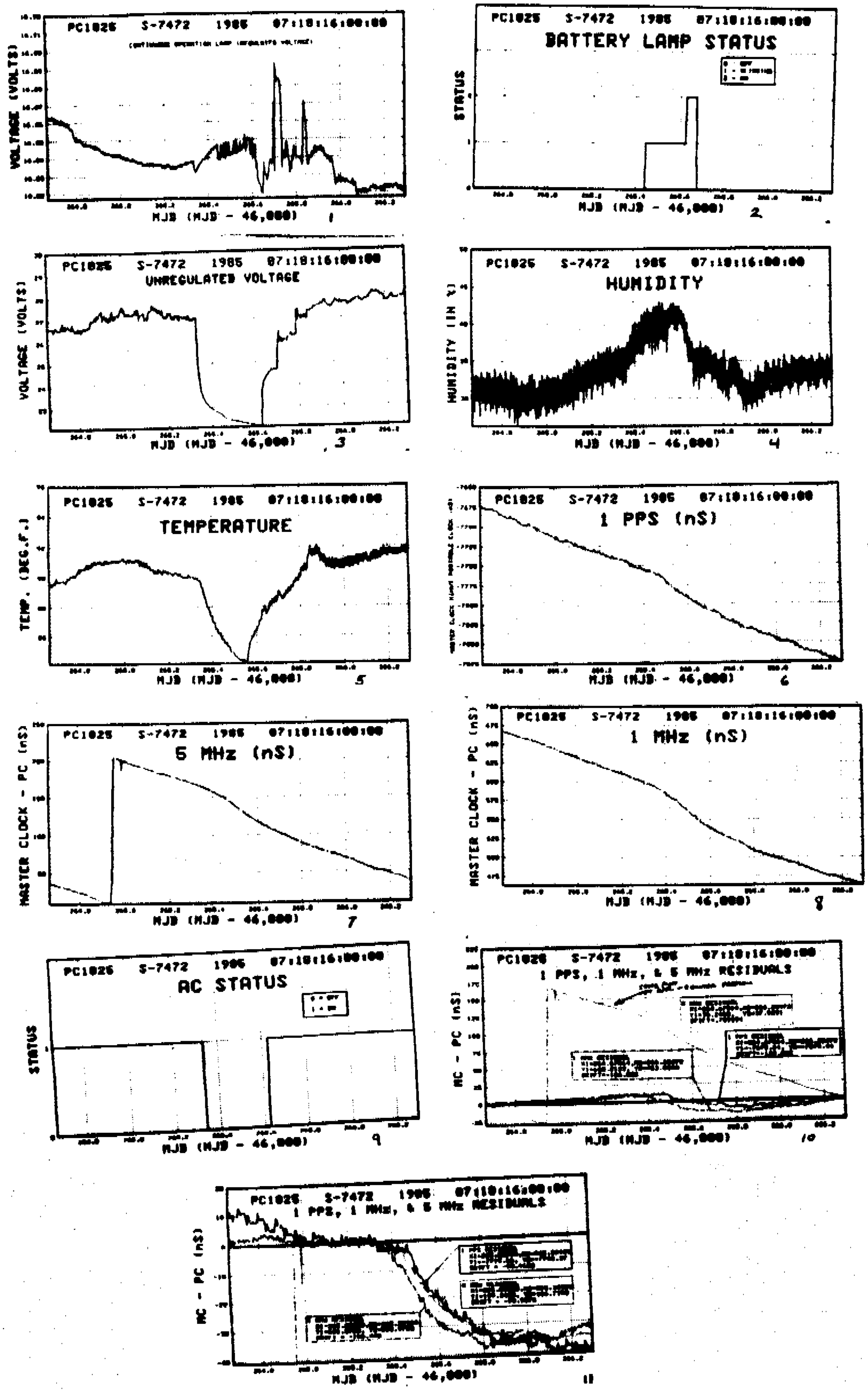
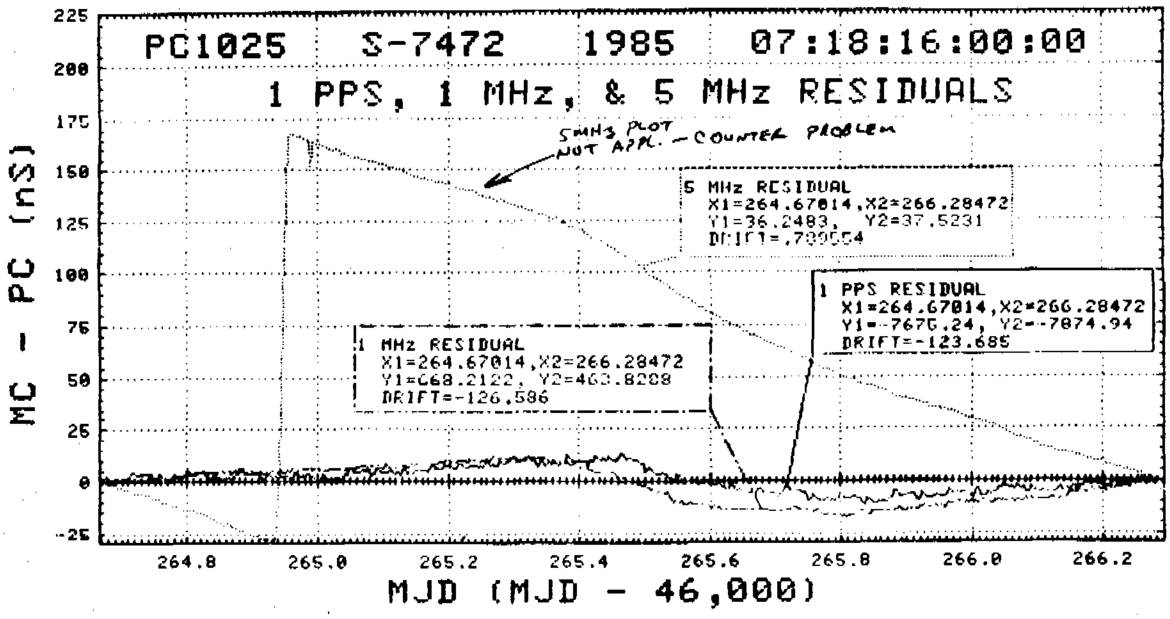

VOLTAGE (VOLTS)
MJD (MJD - 46,000)
BATTERY LAMP STATUS
STATUS
UNREGULATED VOLTAGE
HUMIDITY
HUMIDITY (IN %)
TEMPERATURE
TEMP. (DEG.F.)
1 PPS (nS)
5 MHz (nS)
MASTER CLOCK - PC (nS)
1 MHz (nS)
AC STATUS
1 PPS, 1 MHz, & 5 MHz RESIDUALS
MC - PC (nS)

Figure 8



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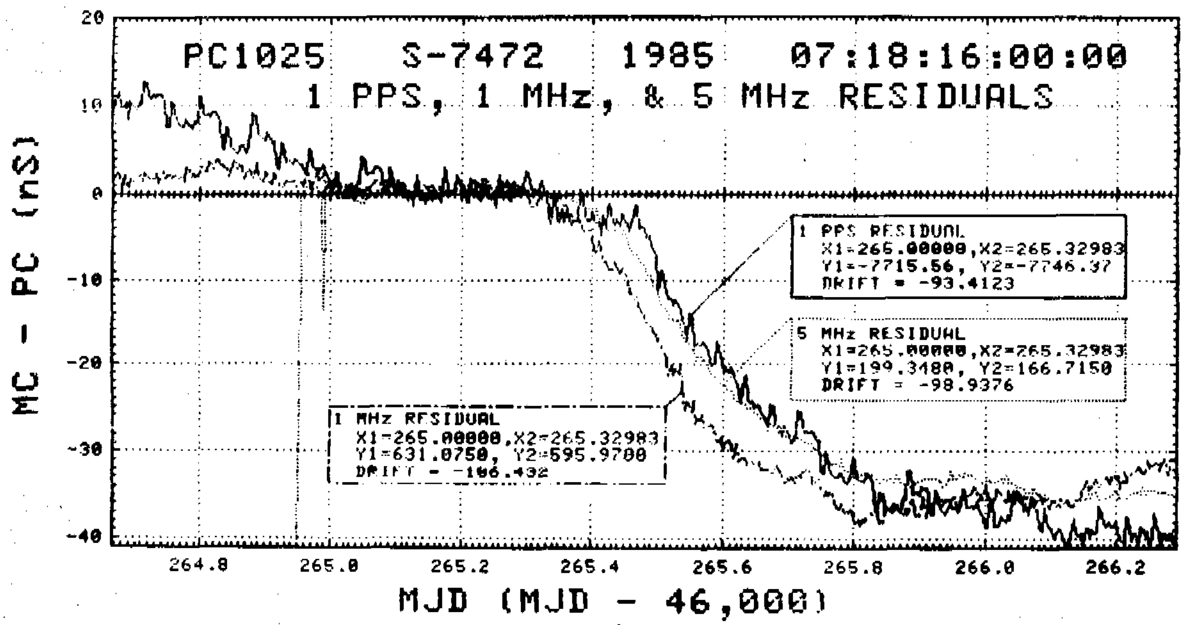

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Figure 9

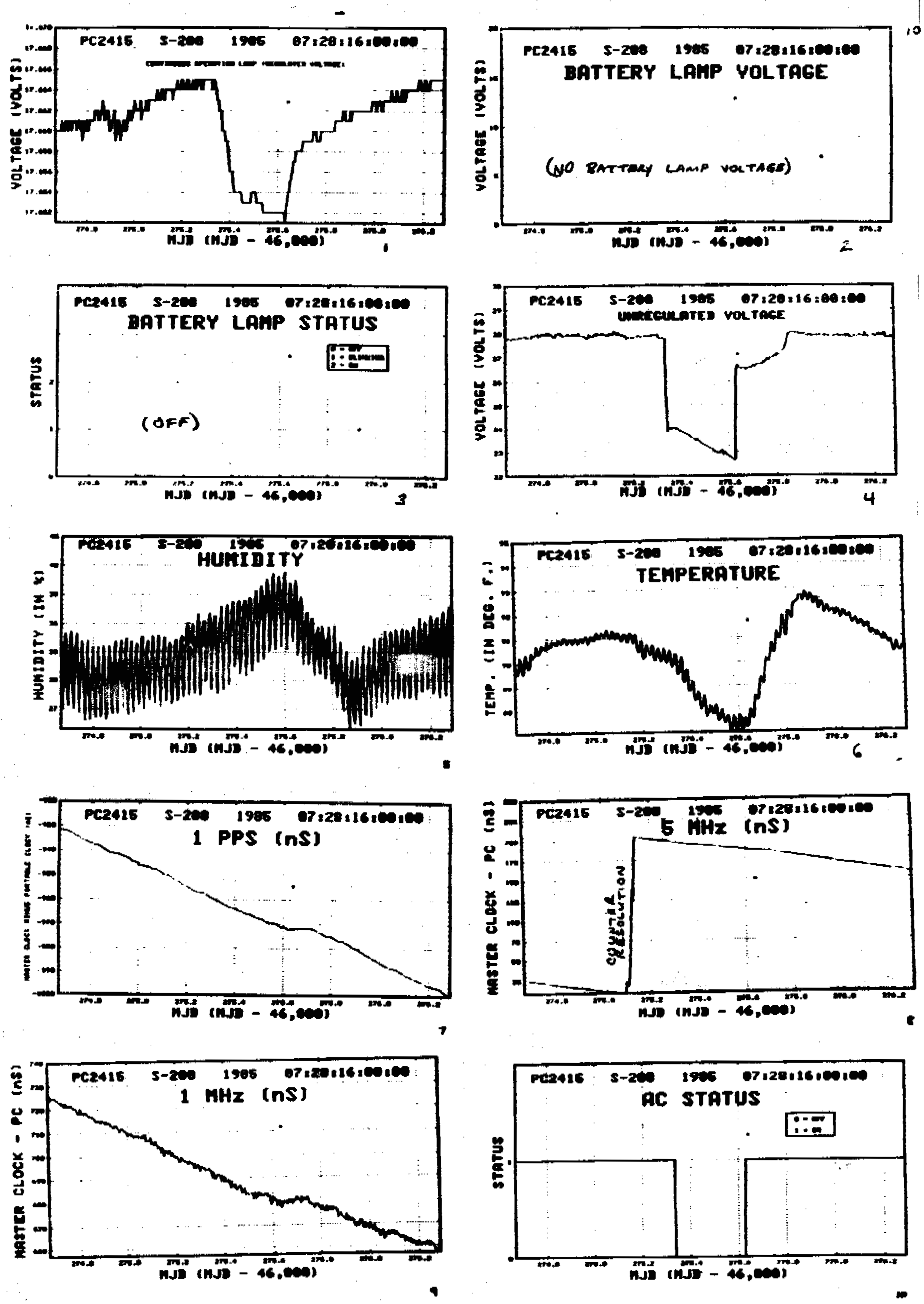
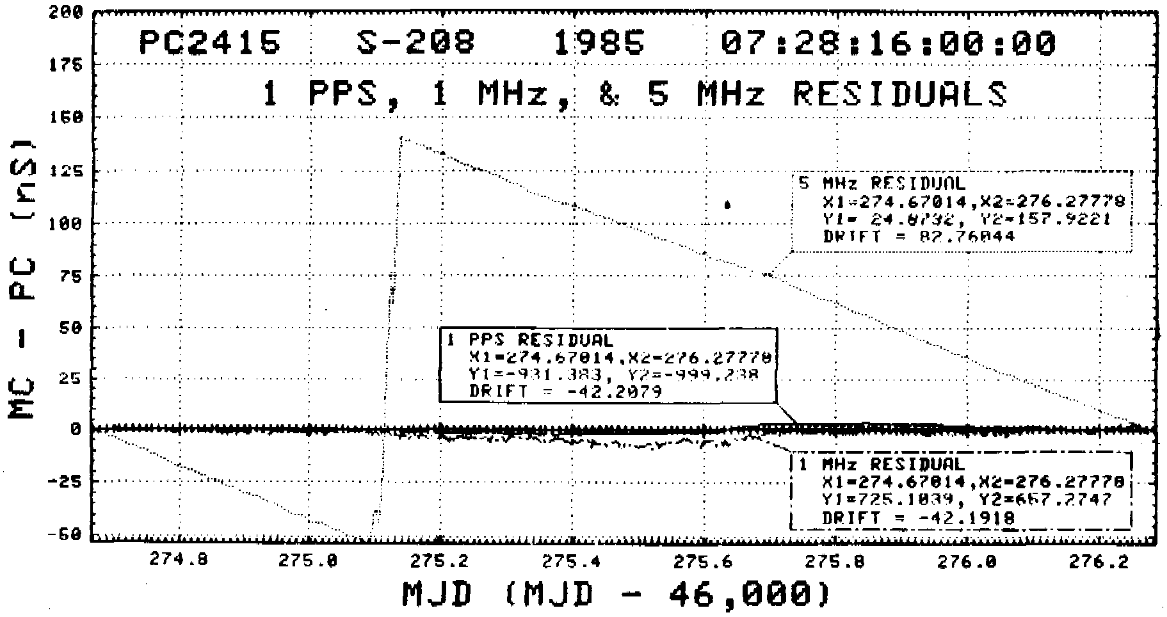

PC2415 S-200 1985 07:28:16:00:00
VOLTAGE (VOLTS)
MJD (MJD - 46,000)
BATTERY LAMP VOLTAGE
(NO BATTERY LAMP VOLTAGE)
BATTERY LAMP STATUS
STATUS
(OFF)
UNREGULATED VOLTAGE
HUMIDITY
HUMIDITY (IN %)
TEMPERATURE
TEMP. (IN DEG. F.)
1 PPS (nS)
5 MHz (nS)
MASTER CLOCK - PC (nS)
COUNTER RESOLUTION
1 MHz (nS)
AC STATUS
1
2
3
4
6

Figure 10



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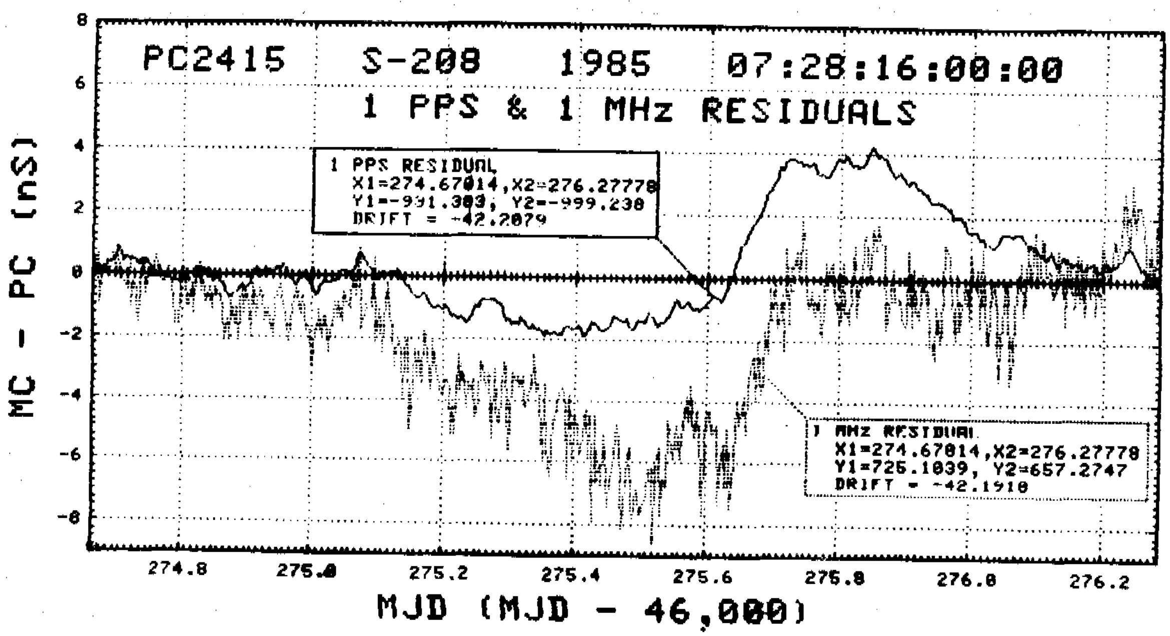

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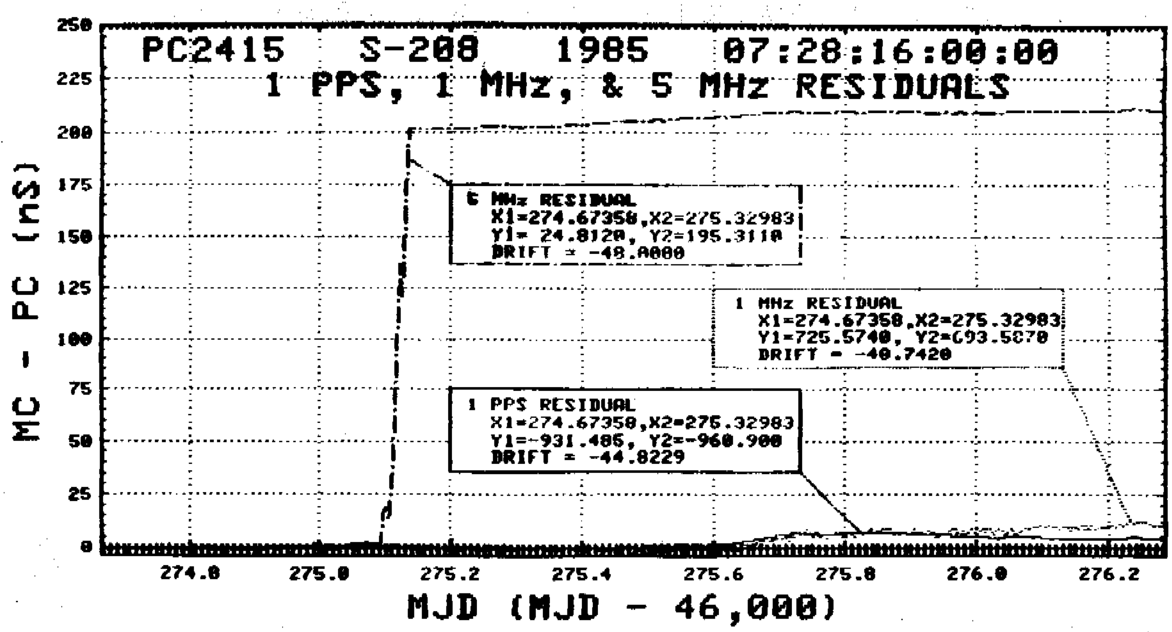
Figure 11



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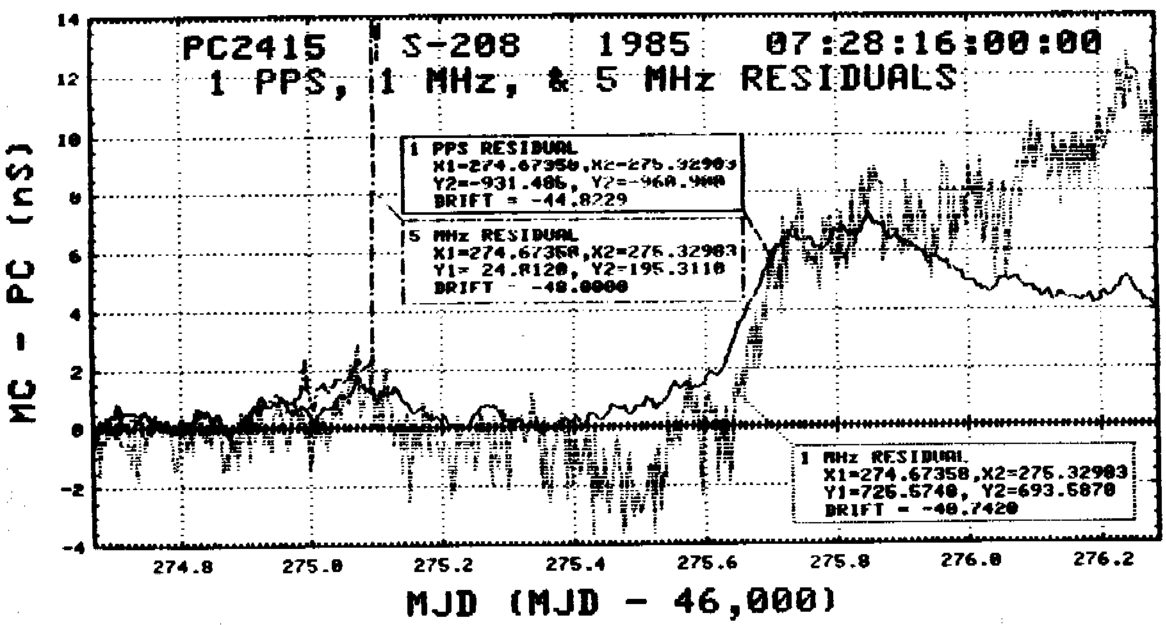

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Figure 12

QUESTIONS AND ANSWERS

UNIDENTIFIED QUESTIONER:
Do you have any feeling for how big the magnetic effect is when reversing the current on the battery pack?

MR. ELSON:
No, as I said, initially we just collected data before we even decided the direction that the test would take. I have not studied the magnetic effect at all.

QUESTIONER:
You haven't done any C-field measurements during the tests?

MR. ELSON:
No, just the outputs.

RICK ENDSLEY, JET PROPULSION LABORATORY:
We have done quite a bit of study on this problem also, and came to pretty much the same conclusions that you have. We took it one step farther and found that the biggest affects were on the C-field regulator from temperature changes due to the rectifiers which were next to it on the printed circuit board. We modified one of our cesiums and did quite a few tests after that change and found that most of the problems went away. We gave these circuit modifications to HP and they are in their new cesium.

LOU MILLER, HEWLETT PACKARD:
I happen to be the production engineer for cesium beam tubes and a consultant to the engineering staff on the instrument itself. The four circuits that you mentioned that were changed were the voltage regulator circuit assembly, the cesium oven controller, which is a module, the battery charger, which is again a printed circuit assembly, and the digital divider, which is a module. It generates the one pulse per second signal. The "funnies" that you saw in the residual on the one pulse per second, we think will be taken care of by the new digital divider. It turns out that the instrument that had that was of the series just before that change occurred. The voltage regulator card and the C-field effects that Mr. Endsley alluded to were my first thought as to what caused the rate change. I checked that, there is a five volt reference that is obtained from a ten volt precision reference, which would have to develop about a ten millivolt change to account for that much change in the C-field. The actual change was actually less than ten microvolts when I went from AC power to battery power at a much lower voltage than you ever allowed it to reach. I assume that that effect is corrected. At the same time that I was doing that, I was monitoring the frequency change. I had about a four parts in ten to the thirteen shift in frequency for that same change in AC power to battery. That turned out to have been the voltage regulator for the hot wire ionizer running out of steam. That caused a phase shift in the instrument which led to that offset. I have brought a prototype that I have tested and which solves the problem. Barry has that and knows how to put it in the instrument, so one of these days he can check its performance. I think that it will solve the problem. Everybody probably wants to know what we are doing about it. There is another problem with that particular circuit. It tends to eat transistors that drive the ionizer circuit and we have had an electrical engineer looking at that for some time. He has identified the cause and has modified the circuit. At the same time we were asking for an increased current range on it so that we could live within the manufacturing

variations in the material that we have to buy to make the ionizer ribbon. That led him to a change in the transformer that produces the voltage for the ionizer. I was able to steal one of the transformers from him an put it in the module that Barry has. It will produce the 3.5 ampere ionizer requirement when the supply drops down to below eighteen volts, at which time every other circuit in the instrument is acting funny. There are some other things that happen that I don't understand yet. We are still working on those.

DAVID ALLAN, NATIONAL BUREAU OF STANDARDS:
First of all, I wonder if the temperature effects which are caused by the changes in heat when you remove the AC supply could cause effects on other things, frequency multipliers and other components.

MR. DAVIS:
The biggest effect, and the one most easily correlated was the temperature. The shape of the response to the AC being turned off and when it was turned on and before and after the battery was recharged are indicative of these effects. I also concluded that, since I had the same basic frequency source, a cesium beam tube and its associated circuitry, the different shapes in the outputs meant that there are other effects. The most obvious is the large temperature change that I did plot. The temperature probe was lying on top of the cesium, not inside the instrument, so the change was much more severe inside the cesium. However, the purpose of this test was just to measure the outputs and look at the data and then determine where to go from there. The test set is portable, it is on wheels, so it can be moved into a more closely controlled vault. We have not even looked at humidity, but we can do that, we can change the temperature, we can run it only on DC and vary the DC voltage. I recognize two secondary effects that cause changes. I am sure that there are more, but we have not identified them yet.

MR. ALLAN:
We have found that quite often temperature gradients are more important than temperature. The last statement, really a question, is why the manufacturers of cesium standards don't use digital dividers which clock the one PPS to the phase of the 5 MHz or the 10 MHz. The phase of those carrier frequencies is much more stable, so that by using digital divider clocking technique, one would have an improved one PPS. This technology works beautifully, so why don't we use it?

MR. WINKLER:
I think that the answer is that the specification calls for this instability. We have to give up being able to adjust the one PPS arbitrarily close. I think that we should give it up, it is an unecssary specification.